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Rapid Assessment of Small Changes to Major Gun and Projectile Dynamic Parameters

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Rapid Assessment of Small Changes to Major Gun and Projectile Dynamic Parameters

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Abstract

The U.S. Navy's 5-in 54-cal. (5"/54) gun system Mark (Mk) 45 was subjected to first-order dynamic analysis tools that allowed rapid assessment of ballistic dispersion of a typical naval high-explosive projectile.

The interior ballistics high-velocity gun version 2 (IBHVG2) modeled the 5-in propelling charge Mk 67, and gun barrel centerline data were obtained from two 5"/54 Mk 19 gun barrels. The "Little RASCAL" program was used to estimate the tipoff angles and angular rates for the Mk 64 5-in projectile, and the "PC-PRODAS" computer program was used to estimate the projectile yaw and yaw rates resulting from the bore and bourrelet clearance. The tipoff angles and rates obtained for the Little RASCAL program were then combined with the yaw data to establish a matrix of possible worst-case conditions of initial projectile yaw and yaw rate.

A total of 32 possible muzzle exit conditions were identified and used as initial conditions for a 6 degrees of freedom trajectory program. The resulting variation in range obtained from the 32 trajectory calculations was used to calculate the range probable error. The results obtained from this relatively simple analysis technique have shown very good correlation with ballistic dispersion measurements made during actual firing tests.

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1. INTRODUCTION

The high cost of prototype fabrication and testing of today's complex weapon systems has placed an increasing emphasis on simulation and modeling to evaluate system design alternatives and effectiveness prior to actual hardware manufacture. In the area of large-caliber gun systems, some of the most expensive tests are those required to determine the ballistic dispersion of the gun and/or its ammunition. Although there are several very sophisticated computer models available today that will accurately predict the dynamic response of large-caliber gun systems during firing, these models typically require precise three-dimensional models of the gun system configuration and its mass properties. Therefore, these models are not well suited to conducting the "sanity check" type evaluations often required to assess the impact of potential design alternatives and/or proposed design modifications in a timely manner.

In a joint government/industry collaboration, the U.S. Army Research Laboratory (ARL) and the Armament Systems Division of United Defense, LP have investigated the feasibility of utilizing the "Little RASCAL" (Erline, Kregel, and Pantano 1990) gun dynamics simulation program in conjunction with "standard" interior and exterior ballistic programs to provide a "desktop" analysis capability to evaluate the ballistic dispersion of intermediate-caliber gun systems. The gun system chosen for analysis in this study was the U.S. Navy's 5-in 54-cal. (5"/54) Mark (Mk) 45 gun mount. The Mk 45 is the main gun armament of the majority of current U.S. surface combatants and is slated to be upgraded in capability as part of the Naval Surface Fire Support (NSFS) program. Therefore, considerable interest exists in obtaining a more detailed understanding of the system-error budget.

The analysis procedure described in this report has been shown to yield reasonable estimates of the ballistic dispersion of an intermediate-caliber indirect-fire weapon, offers a relatively simple method for obtaining "first-order" estimates of the impact of proposed design changes to either the weapon or its ammunition, and can provide a useful tool for gun system designers to assess the potential impact of small changes to major parameters affecting gun and projectile dynamics.

2. BACKGROUND

This study was based on two ARL-developed computer models: the Interior Ballistics High-Velocity Guns version 2 (IBHVG2) (Anderson and Fickie 1987) program, the Little RASCAL gun dynamics program, plus the commercially available projectile design and analysis program PRODAS.*

IBHVG2 is a lumped-parameter, interior ballistics computer code. The code, which was developed at ARL, is an updated version of the classic Baer-Frankle interior ballistic code. IBHVG2 is used to calculate interior ballistic trajectories, including gas pressure, projectile displacement, and projectile velocity as a function of time. IBHVG2 was used to compute the interior ballistic cycle of the standard 5-in propelling charge Mk 67. The Mk 67 charge is designed to produce a nominal exit velocity of 2,650 ft/s (808 m/s) with a 70-lb (31.75 ks) projectile. The projectile velocity and breech pressure vs. time data computed by IBHVG2 were used as input to the Little RASCAL gun dynamics program.

The Little RASCAL is a comprehensive modeling code for predicting lateral gun dynamics and projectile dynamics. When fired, the bore-riding projectile undergoes a complex sequence of mechanical and gas dynamic interactions on its way out the barrel. The Little RASCAL gun and projectile dynamics program is capable of simulating the inertial loading conditions brought about by the projectile interacting with the barrel in a plane as it accelerates the length of a gun tube's unique centerline. Thus, in tracking the projectile interacting with the barrel, the initial launch conditions of the projectile at shot exit can be predicted. Projectile pitch and pitch rates, as well as muzzle motion, are calculated and available for use as input to the exterior ballistic programs.

The Little RASCAL gun and projectile dynamics program is a dynamic displacements code employing a direct structural dynamics analysis approach to the simulation of firing a projectile from a gun. Both the gun system and the projectile are modeled using a series of equally spaced

* PRODAS is a commercial multifunction ballistics program developed by ARROW Tech., Inc.

cylindrical elements. Nodes are centered and assigned equivalent mass and stiffness values based on standard engineering formulae. Inertial forces and flexural forces are calculated using this simplified description. Flexure at each node is approximated by a second-order finite difference method, which allows the bending forces to be computed. Transverse nodal accelerations caused by these forces are integrated with respect to time to obtain transverse nodal velocities and integrated again to obtain lateral node displacements. Loads induced by pressure effects, mounting conditions, breech center of gravity offset, and the projectile interaction forces with the barrel are accounted for in the Little RASCAL program. All forces are then integrated by a predictor-corrector technique stabilized by a numerically stiff ordinary differential equation solver (Kregel and Lortie 1973).

The gun system, which includes the breech, barrel, and two gun supports, and the projectile system are two separate models. They are accounted for individually, except for a variational algorithm that handles their interaction. The interaction of the projectile with the barrel occurs through contact points. The two contact points defined on the projectile are usually positioned where they occur geometrically. The two projectile contact point positions on the barrel are dynamic and change as the projectile traverses the bore. The gun system model and the projectile model are two separate, flexible entities with each projectile contact point requiring a user-defined spring constant. The spring constants serve to define the interface loads between the projectile model and the gun model.

The Little RASCAL program has proven that simple modeling techniques in which the primary components of a gun system are included can produce reasonably accurate results in a timely manner. The code is generic enough so that almost any gun system and projectile can be modeled in a simple manner. Gun dynamics predictions made by Little RASCAL of barrel motion have been shown to agree quite well with experimental results over a wide range of gun system size and type (Erline and Kregel 1988).

The PRODAS program is a multifaceted projectile analysis package. The principal features of the program used for this study were the muzzle exit analysis feature and the six degree-of-freedom (6DOF) trajectory model. The muzzle exit segment of PRODAS was used to compute the initial

muzzle exit tipoff angle and tipoff rate resulting from the clearance between the projectile and the bore of the gun. The 6DOF trajectory model was used to determine the effect on achieved range of various initial pitch and yaw angles and angular rates.

The projectile geometry and mass properties used throughout the study were based on the standard 5-in Mk 64 projectile body (Figure 1) with high-explosive load and Mk 73 CVT proximity fuze. The mass properties of the projectile are summarized in Table 1.

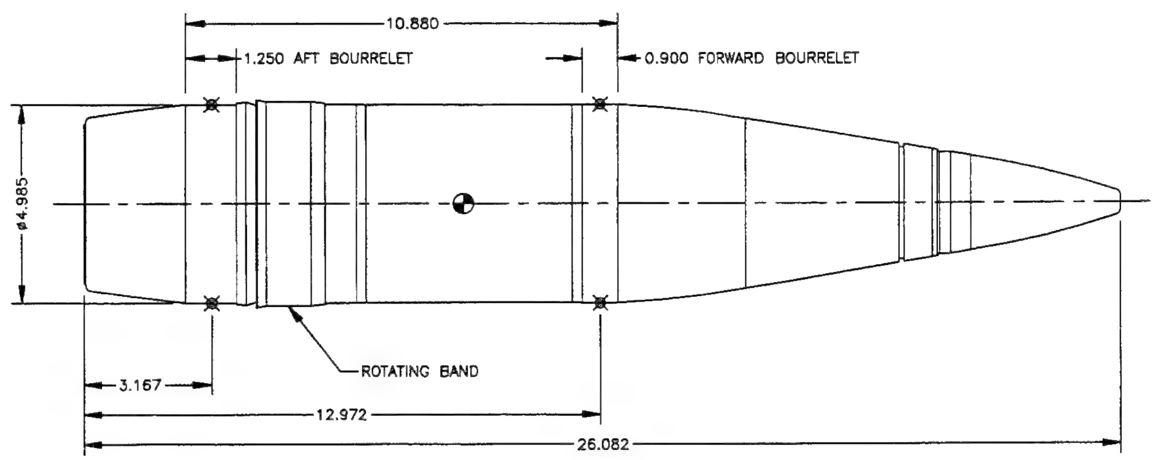

Figure 1. Mk 64 5-in projectile.

Table 1. Projectile Mass Properties

Weight	68.49 lb	(31.07 kg)
Center of Gravity From Nose	16.56 in	(420.6 mm)
Axial Moment of Inertia	240.83 lbm-in^2	(16.97 kg-m^2)
Transverse Moment of Inertia	2803.50 lbm-in^2	(2299.71 kg-m^2)

As with any gun dynamics model, the accuracy of the results obtained from the Little RASCAL model is dependent upon detailed, precise knowledge of the weapon being analyzed. Since the Mk 45 gun mount has been in production for over 20 years, a considerable volume of detailed information concerning the geometry, mass properties, and stiffness of various system components was available to facilitate the modeling process. This was also true for the ammunition components. The single area where detailed information did not exist was the gun barrel. Although dimensional and mass property data existed for the 5-in gun barrel Mk 19, there was little, if any, information on the centerline variations existent in previously manufactured gun barrels. To overcome this lack of information, centerline measurements of two Mk 19 Mod 2 gun barrels, serial numbers (S/N) 518 and 17343, were made by the ARL author using laser measuring equipment. A third gun barrel, S/N 17423, was also measured; however, data from this barrel became available too late to be included in this study.

The original objective of this study was to determine the ability of the Little RASCAL program to accurately predict the dynamic response of the Mk 45 gun mount during firing for the purpose of gaining a greater understanding of the total error budget of the system. However, as the analysis proceeded, it became apparent that the analysis methodology being employed could be utilized as a relatively simple means of assessing the potential impact of changes to certain key system design parameters upon the ballistic dispersion of the system.

3. APPROACH

The analysis methodology developed during this study involves a four-step process: (1) The Little RASCAL model is used to predict the projectile pitch and yaw angles and angular rates resulting from the dynamic response of the system during firing; (2) The tip off angle and angular rate resulting from the in-bore yaw of the projectile are computed for both nominal and maximum projectile-clearance conditions. These muzzle exit conditions are combined numerically with the Little RASCAL results to obtain a set of initial projectile launch conditions to be used with the 6DOF trajectory model; (3) The 6DOF trajectory model is used to compute the range to impact for each of the initial conditions defined in step 2; (4) The results of the trajectory calculations are

tabulated, and the mean and standard deviation of the achieved range are computed to give an estimate of the ballistic dispersion that would result from the system configuration being modeled.

The Little RASCAL modeling process involves describing the projectile, projectile interior ballistics, and the gun system. The projectile is described by its geometry and mass properties, plus a definition of the location and spring constant for each of the two contact points between the projectile and the gun barrel. The interior ballistics information consists of the projectile velocity vs. time history for the in-bore cycle. The gun system information required includes the geometry and mass description of the gun barrel and breech along with breech center of gravity offsets, if any, trunnion and elevation support locations, and their equivalent spring constants. The final gun system data requirement is the data describing the variations in the centerline of the gun barrel.

A simplified schematic representation of the gun system, as modeled in the Little RASCAL program, is shown in Figure 2. The breech assembly of the Mk 45 has a weight of 2,344 lb (1,063 kg), and its center of gravity is offset 0.141 in (3.58 mm) vertically and 0.0302 in (0.77 mm) horizontally. The trunnion supports are located 19 in forward of the rear face of the breech assembly and were assigned a spring constant of 3,200,000 lb/in (57.15e+6 kg/m). The effective elevation support of the gun assembly is located 17 in aft of the trunnion and was assigned a spring constant of 135,800 lb/in (2.44e6 kg/m). As previously stated, the centerline variations of two 5-in Mk 19 Mod 2 gun barrels, S/N 518 and S/N 17343, were measured by ARL personnel for use during this study. The vertical and horizontal centerline deviations of the two barrels are shown in Figures 3 and 4.

The muzzle exit conditions computed by the PRODAS program include the magnitude of the tipoff angle and tipoff rate resulting from the bore to bourrelet clearance and spin of the projectile. The dimensional tolerances on the bourrelet of the projectile and the bore of gun barrel were examined to define the extreme clearance conditions likely to occur in fielded systems and the tipoff angle and angular rates for minimum and maximum clearance conditions computed. Since the orientation of these exit conditions (i.e., up, down, left, right, etc.) is random in nature, a baseline

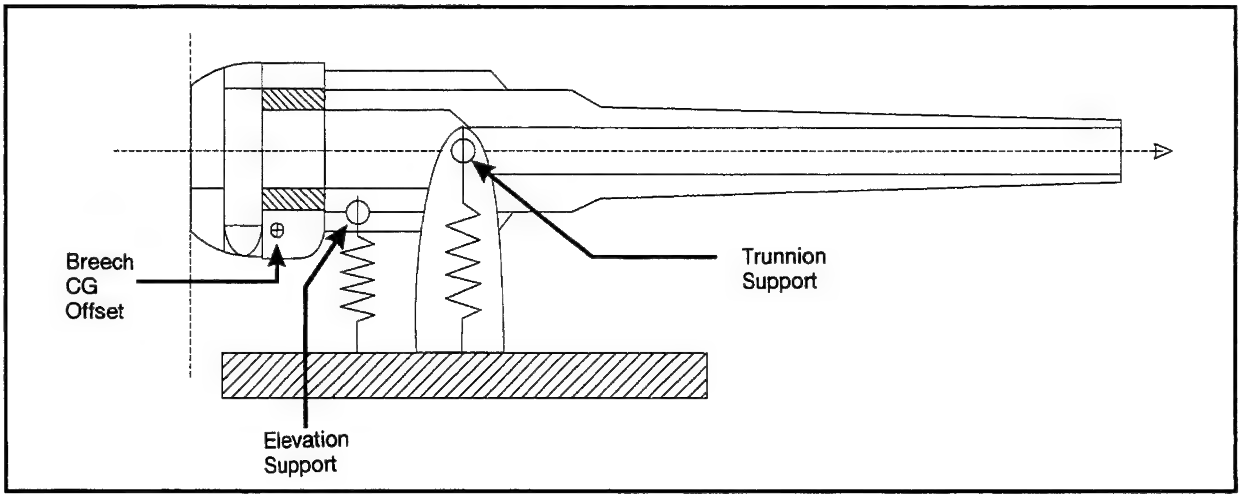

Figure 2. Gun system model.

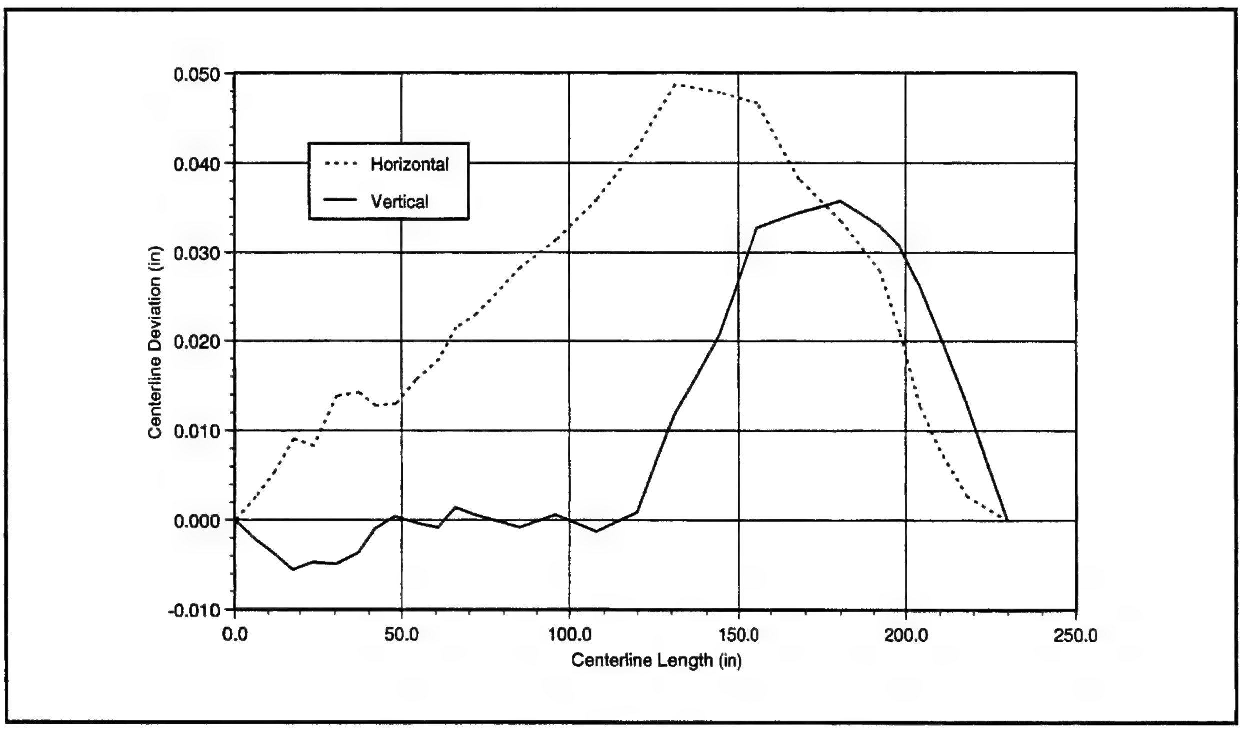

Figure 3. Gun barrel S/N 518 centerline data.

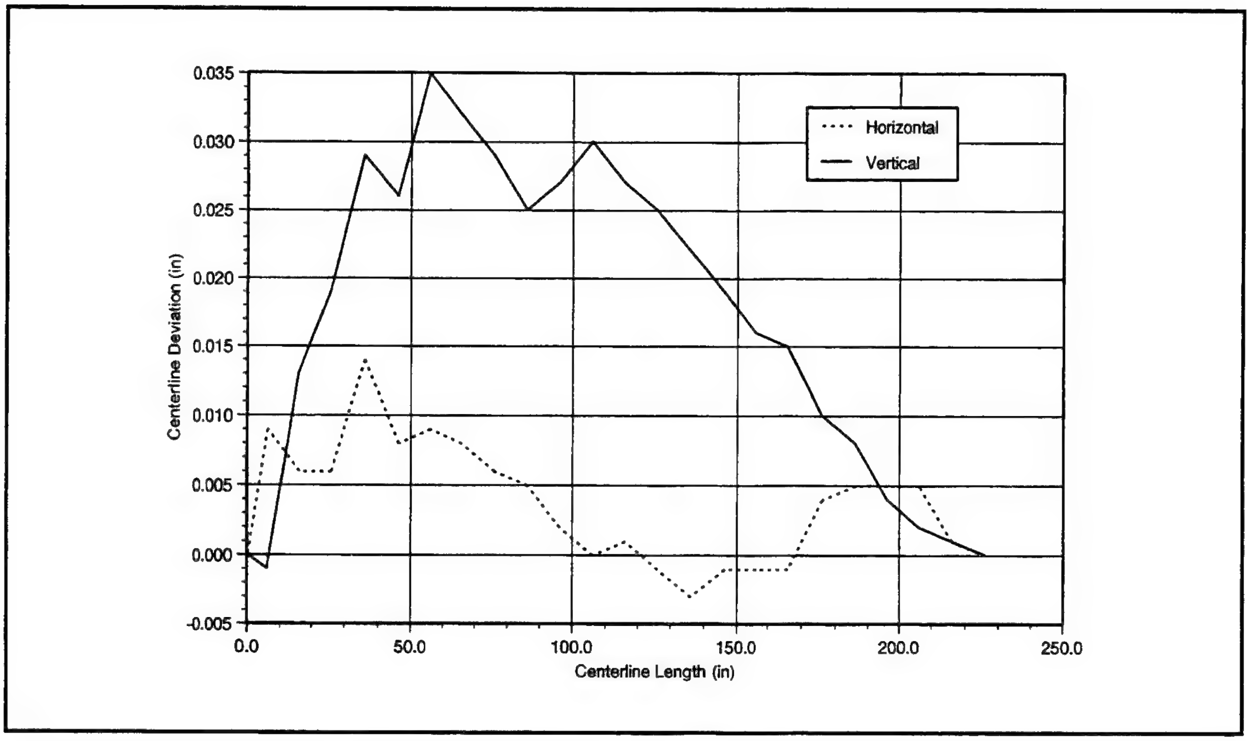

Figure 4. Gun barrel S/N 17343 centerline data.

analysis. These combinations of pitch and yaw angle and angular rate were combined numerically with the results from the Little RASCAL program to produce a matrix of initial launch conditions for the 6DOF trajectory model. Thus, a total of 64 possible launch conditions was established for each case to be analyzed.

Prior to beginning the analysis, the 6DOF trajectory model was "calibrated" by adjusting the projectile input data to obtain range results under standard conditions that corresponded to published information (Naval Sea Systems Command 1985) on the range performance of the 5"/54 gun system. Once the trajectory model was calibrated, the launch condition matrices were used to generate input data files for the trajectory model. Computation time for the test case trajectories varied between 2 and 20 min, depending on the gun elevation being used and the speed of the individual computer.

To facilitate analysis and manipulation of the data, the trajectory results were compiled in a computer spreadsheet. This approach permitted rapid computation of various statistical data such as the mean and standard deviation of the range results and plotting of the data.

4. RESULTS

The initial series of simulations performed using the Little RASCAL model consisted of determining the dynamic response of each gun barrel at seven different gun elevation angles. The elevation angles chosen corresponded to nominal gun ranges of 1,000 (914 m); 2,000 (1,828 m); 5,000 (4,572 m); 7,500 (5,212 m); 10,000 (9,140 m); 15,000 (13,716 m); and 20,000 (18,280 m) yd.

The results obtained from this initial modeling of the Mk 45's dynamic response at various elevation angles were used to assess the ability of methodology established for this study to provide a reasonable estimate of the ballistic dispersion that result from actual gun firings. Trajectory calculations were made using the results from both barrel centerlines at each evaluation angle. The range standard deviation obtained in each case was then compared to the best available estimates (Updike 1996) of actual gun system performance under proving ground conditions. The results of this assessment are shown in Figure 5.

The proving ground range dispersion values shown in Figure 5 are based on post-test analysis of a large volume of firing data collected by the Naval Surface Warfare Center/Dahlgren Division over the last 20+ years from numerous 5"/54 gun systems under various firing conditions. These values are derived during the post-test data reduction process and may be characterized as the standard deviation of the residual uncertainty that exists between the observed range of each around and the value computed when all known conditions (i.e., meteorological conditions, projectile weight, actual muzzle velocity, etc.) are factored into the standard 5"/54 fire-control equations. It has also been noted that observed ballistic dispersion of the 5"/54 gun system has been declining in recent years. This is evident in the results of a recent shipboard ammunition effectiveness test (Jones and Updike 1995) conducted under closely controlled conditions at a gun tartet range of approximately 18,000 yd; the observed standard deviation error in range was 48 yd (12 yd less than

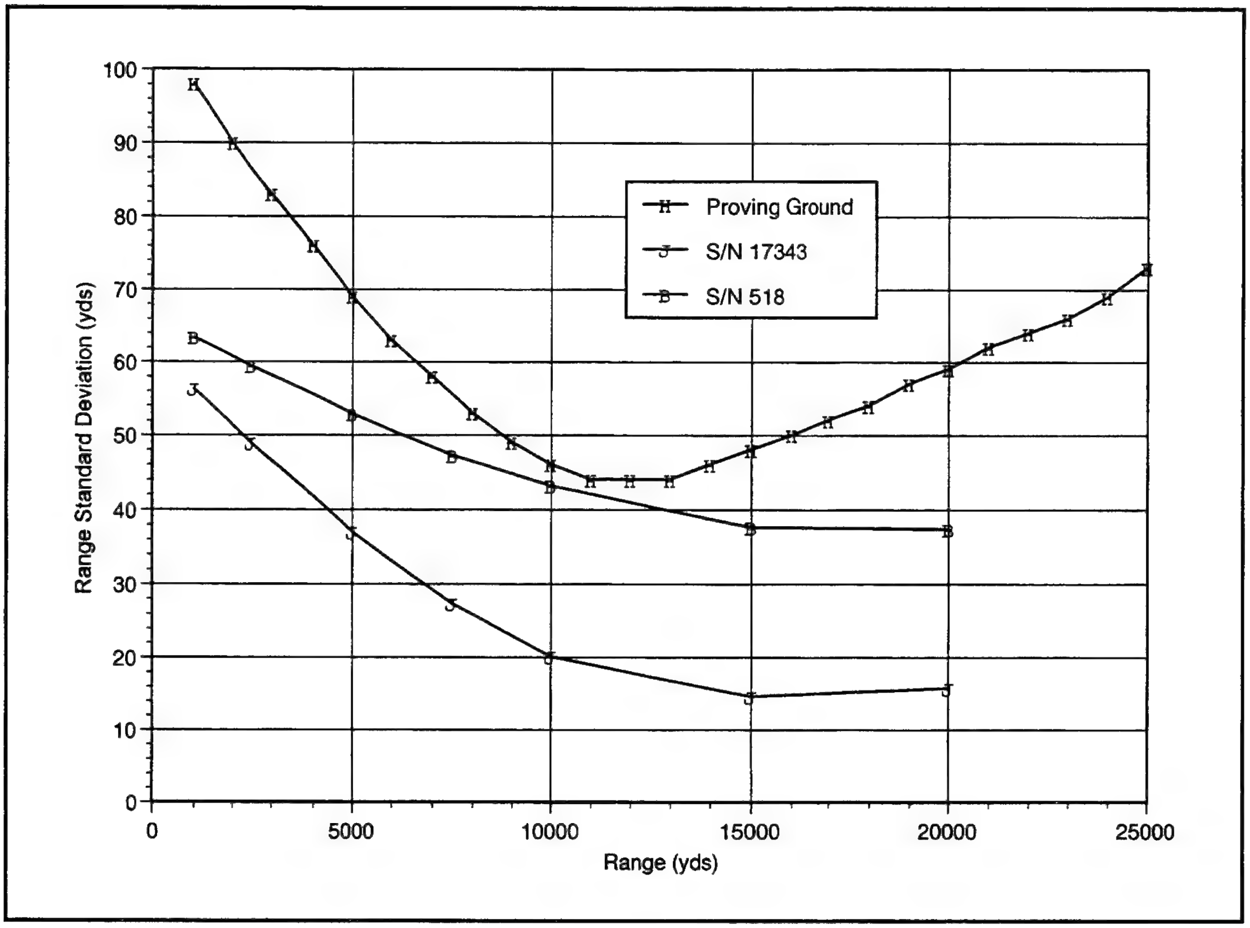

Figure 5. Calculated and proving ground range dispersion.

the established proving ground value). While the reasons for this decline in dispersion are beyond the scope of this report, a major contributing factor could be the improvements in dimensional consistency achieved in projectile bodies manufactured using numerically controlled machining processes.

The distinctive "U," or "bathtub," shape of the proving ground range dispersion curve is characteristic of most naval gun systems. Because naval guns employ a single service charge for both direct- and indirect-fire targets, variations in the departure angle of the projectile tend to be the dominate cause of range dispersion at short range, while factors that affect the drag and flight characteristics of the projectile (i.e., dimensional variations, surface finish, center-of-gravity location,

inertia, etc.) are the dominate source of error at long range. In addition, transient meteorological effects have a greater impact on the long-range trajectories.

A further detail that must be considered when interpreting the results illustrated in Figure 5 is the effect on the projectile initial tipoff angle and angular rate caused by the torsional response of the gun barrel due to the rifling reaction as the projectile is spun up during the ballistic cycle. This response is not modeled in the Little RASCAL program and could account for the underprediction of dispersion at the shorter ranges.

In light of the considerations discussed previously and the limited amount of barrel centerline data available, it was concluded that the analysis methodology developed for this study was providing a reasonably (accurate first-order indication of range dispersion resulting from the dynamic response of the gun). In addition, further analysis of the trajectory results revealed that the average achieved range of rounds fired from gun barrel S/N 518 was always less than that achieved by gun barrel S/N 17343 as illustrated in Figure 6.

While it has frequently been observed that some guns are "long shooters" while others are "short shooters" and that retubing can change a gun from a long shooter to a short shooter and vice versa, the cause of this phenomenon has never been adequately explained or investigated. Although the limited sample size used in this study precludes any definitive conclusions concerning the cause of this phenomenon, the authors feel that further investigation of the effect of gun barrel centerline variations on average achieved range could lead to a more thorough understanding.

Encouraged by these initial results, the authors set out to determine if the analysis technique could be used to characterize the effect on ballistic dispersion of changes to major system design parameters. The system parameters chosen for further analysis were the effective spring constants of the gun trunnions, the elevation support structure, and the forward and aft bourrelets of the projectile body. Since design changes to both the trunnions and elevation drive of the Mk 45 gun

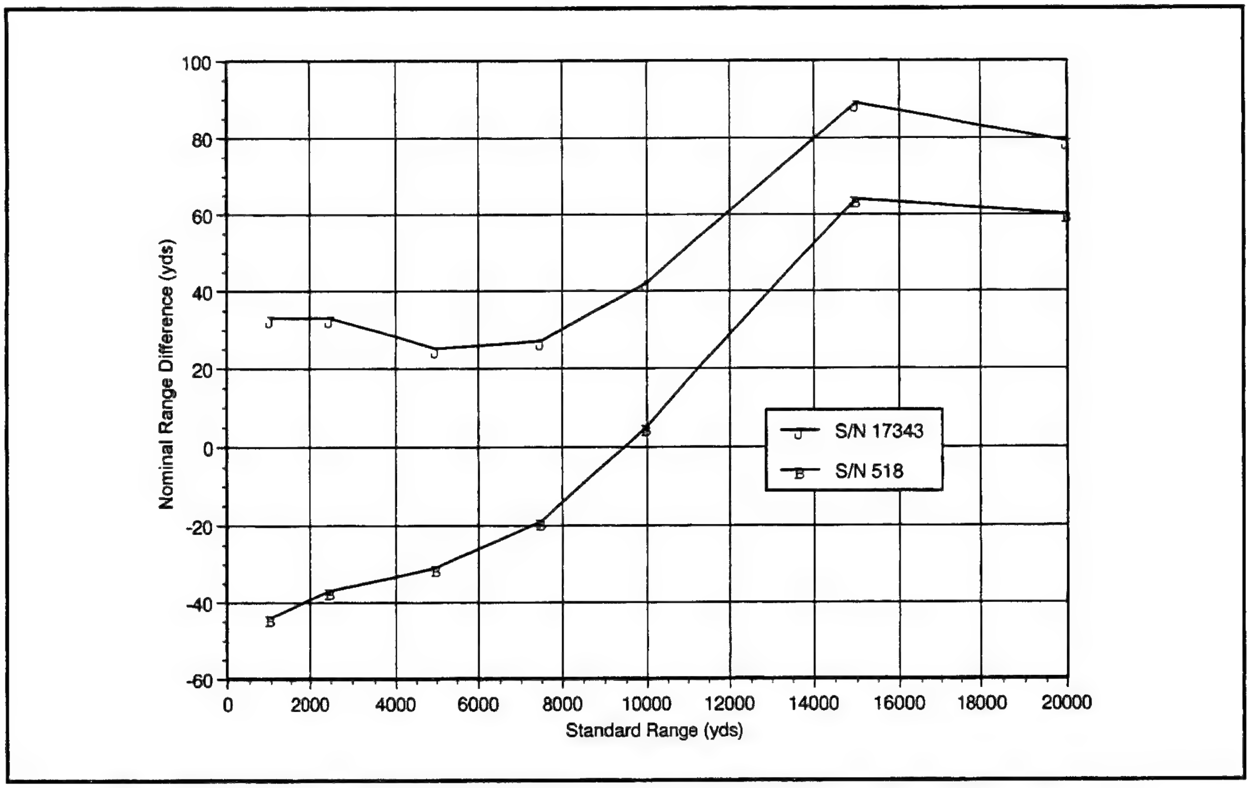

Figure 6. Achieved range differential of gun barrels S/Ns 518 and 17343.

mount are currently being considered as part of the Naval Surface Fire Support upgrade package, the potential impact of changes in these components on ballistic dispersion was of particular interest. Although the significance of accurate estimates of projectile body spring constants on Little RASCAL analysis results has been previously investigated (Erline 1991), the impact of changes or variations in these physical characteristics of the projectile upon the ballistic dispersion of indirect-fire weapons has not been explored.

To assess the utility of the analysis methodology in the characterization of the sensitivity of system ballistic dispersion to variations in the identified system parameters, additional calculations were conducted using the range of values shown in Table 2. Each parameter was varied over the range of values while all the others were held constant at the baseline values previously established for the system. Separate calculations were conducted for each of the two gun barrel centerlines.

Table 2. System Parameters Varied During Analysis

Parameter	Spring Constant lb/in (kg/m)				
	Lower Values		Baseline	Higher Values	
Trunnions	1.92e+6 (34.29e+6)	2.24e+6 (40.06e+6)	2.72e+6 (48.57e+6)	3.20e+6 (57.15e+6)	—
Elevation Support	109,440 (1.95e+6)	123,120 (2.20e+6)	135,800 (2.43e+6)	150,480 (2.69e+6)	164,160 (2.93e+6)
Fwd Bourrelet	0.5e+6 (8.93e+6)	0.8e+6 (14.29e+6)	1.18e+6 (21.07e+6)	2.0e+6 (35.72e+6)	3.0e+6 (53.57e+6)
Aft Bourrelet	0.5e+6 (8.93e+6)	0.8e+6 (14.29e+6)	1.08e+6 (19.28e+6)	2.0e+6 (35.72e+6)	3.0e+6 (53.57e+6)

The range of values chosen for the trunnions and the elevation support was based on engineering experience and the results of numerous shock and vibration analyses and tests that have been conducted on the Mk 45 gun mount since its introduction to the fleet in the early 1970s. The range of spring constants for the projectile bourrelets was based on test results from two Mk 64 projectile bodies and data collected by ARL on the radial stiffness of 120-mm tank projectiles (Lyon 1994). The results obtained from the Little RASCAL model for the variations of the gun mount parameters are shown in Table 3, and the results for variations of the projectile parameters are shown in Table 4.

The small changes in projectile initial conditions that resulted from rather large changes in the spring constants of the gun trunnions and elevation support would seem to indicate that the ballistic dispersion of the Mk 45 gun system is relatively insensitive to major changes in these parameters.

The changes in the initial projectile pitch and yaw angles and angular rates resulting from the changes in the spring constants of both the forward and aft bourrelets are shown in Table 4.

The dynamic shape of the two gun barrels during firing with the baseline initial conditions is shown in Figures 7 and 8. Each figure illustrates the shape of the barrel when the projectile has

Table 3. Gun Mount Parameter Variation Results

Parameter	Barrel S/N	Support Stiffness (lb/in)	Pitch Angle (rad)	Yaw Angle (rad)	Pitch Rate (r/s)	Yaw Rate (r/s)
Elevation Support	518	164,160	6.9920e-04	6.7707e-04	1.7406	0.4797
		150,480	6.9905e-04	6.7707e-04	1.7405	0.4798
		135,800	6.9871e-04	6.7707e-04	1.7404	0.4798
		123,120	6.9876e-04	6.7707e-04	1.7403	0.4798
		109,440	6.9816e-04	6.7707e-04	1.7402	0.4798
	17343	164,160	−7.7922e-04	4.9129e-04	−0.8651	1.5032
		150,480	−7.7956e-04	4.9129e-04	−0.8656	1.5032
		135,800	−7.7990e-04	4.9130e-04	−0.8661	1.5032
		123,120	−7.8023e-04	4.9131e-04	−0.8666	1.5032
		109,440	−7.8058e-04	4.9131e-04	−0.8671	1.5032
Trunnions	518	3,200,000	6.9871e-04	6.7707e-04	1.7404	0.4798
		2,720,000	7.0022e-04	6.7708e-04	1.7412	0.4798
		2,240,000	7.0154e-04	6.7709e-04	1.7419	0.4798
		1,920,000	7.0241e-04	6.7709e-04	1.7423	0.4798
	17343	3,200,000	−7.7990e-04	4.9130e-04	−0.8661	1.5032
		2,720,000	−7.7990e-04	4.9132e-04	−0.8662	1.5032
		2,240,000	−7.7992e-04	4.9133e-04	−0.8663	1.5032
		1,920,000	−7.7991e-04	4.9134e-04	−0.8663	1.5032

traveled three-fourths of the distance to the muzzle, seven-eighths of the distance to the muzzle, and at muzzle exit. The reference for gun barrel motion in these figures is as follows: at time zero all nodal displacments are zero. The dynamic response of the two gun barrels is unique to their individual centerline variations, as shown in Figures 7 and 8. These unique reaction characteristics are also evident in the transverse velocity of the gun muzzle during the in-bore cycle. As can be seen in Figures 9–12, the frequency and amplitude of the transverse velocity response shift with changes in the spring constant of the forward bourrelet of the projectile. This frequency shift is due to a change in the projectile's rigid-body rocking modes. Since there are two rocking modes (Thomson 1981), changing the spring constants of projectile bourrelets changes the response of the gun barrel.

Table 4. Projectile Parameter Variation Results

Parameter	Barrel S/N	Support Stiffness (lb/in)	Pitch Angle (rad)	Yaw Angle (rad)	Pitch Rate (r/s)	Yaw Rate (r/s)
Fwd Bourrelet	518	3,000,000	1.7604e-04	3.6752e-03	-4.4191	1.5883
		2,000,000	1.2332e-03	3.7083e-03	-1.4797	6.1585
		1,185,000	6.9871e-04	6.7707e-04	1.7404	0.4798
		800,000	-4.0800e-04	1.3737e-03	-0.3266	-1.6183
		500,000	-2.8924e-04	1.9709e-03	-3.3228	-0.5196
	17343	3,000,000	1.7451e-03	2.7548e-04	-0.5799	3.4469
		2,000,000	1.5485e-03	2.0303e-03	3.9567	0.1358
		1,185,000	-7.7990e-04	4.9130e-04	-0.8661	1.5032
		800,000	5.5708e-04	1.3142e-03	-0.0378	-1.8546
		500,000	1.3455e-04	1.8419e-04	1.5311	0.2972
Aft Bourrelet	518	3,000,000	1.0206e-04	7.6987e-04	1.0323	4.1891
		2,000,000	8.3561e-04	5.9081e-04	2.1809	1.0394
		1,085,000	6.9871e-04	6.7707e-04	1.7404	0.4798
		800,000	4.7562e-04	9.9157e-04	1.8221	-0.7687
		500,000	8.1551e-05	1.5270e-04	1.5868	-0.1344
	17343	3,000,000	-6.9767e-04	9.4122e-04	0.6385	2.2155
		2,000,000	-7.2585e-04	8.1648e-04	-0.3713	3.4534
		1,085,000	-7.7990e-04	4.9130e-04	-0.8661	0.4798
		800,000	-6.4252e-04	5.0799e-04	-1.2817	0.2990
		500,000	3.4813e-04	2.1200e-03	0.8365	1.6513

From all of the results generated during this study, it was noted that the changes in the spring constant of the forward bourrelet produced much larger changes in the dynamic response of the system than changes to the spring constant of the aft bourrelet. The dominant influence of the forward bourrelet results from several factors, the most obvious being that the forward bourrelet is the first point on the projectile body to encounter the variations in the barrel, and that the center of gravity of the projectile is closer to the forward bourrelet.

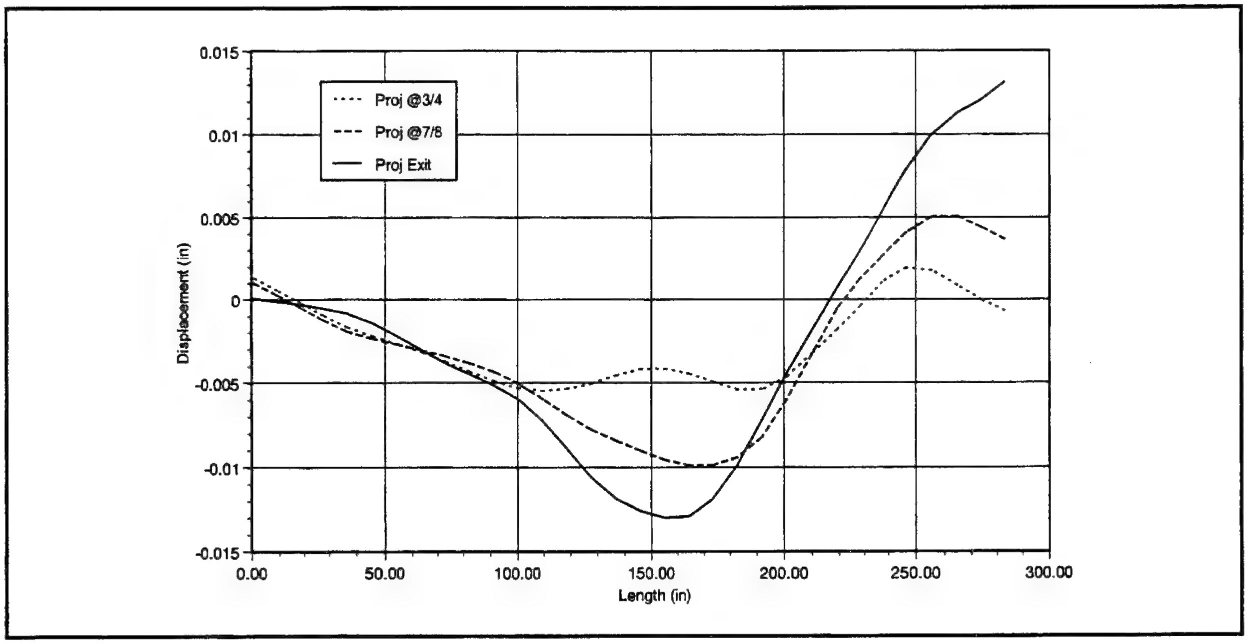

Figure 7. Dynamic shape of barrel S/N 518 during firing.

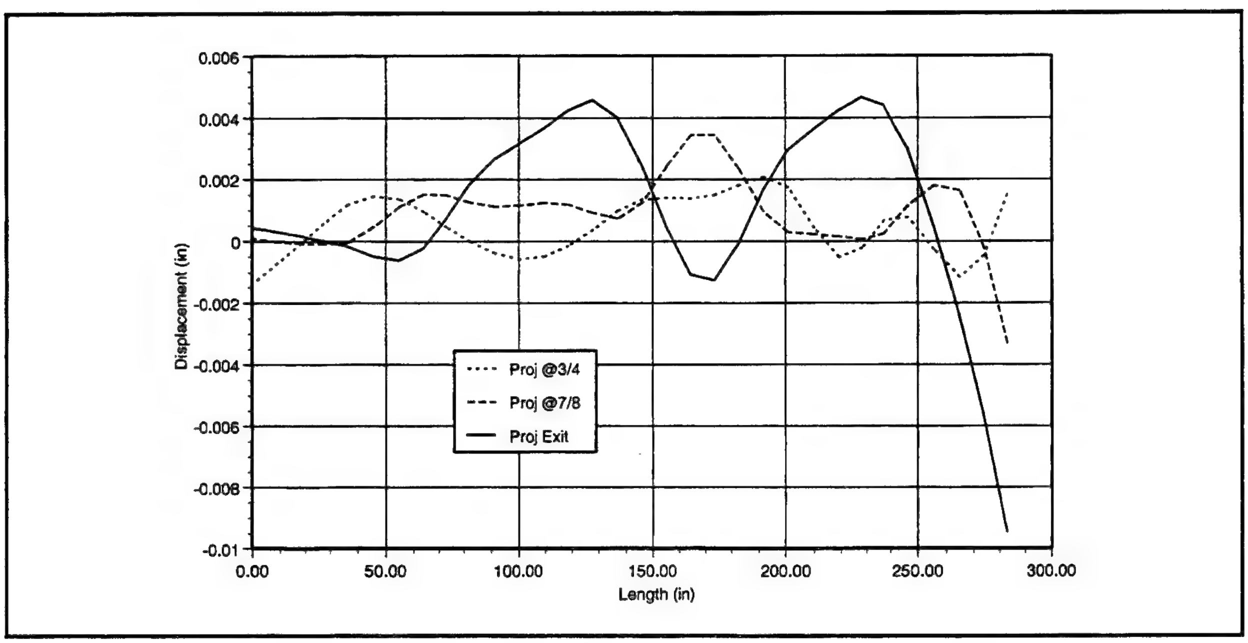

Figure 8. Dynamic shape of barrel S/N 17343 during firing.

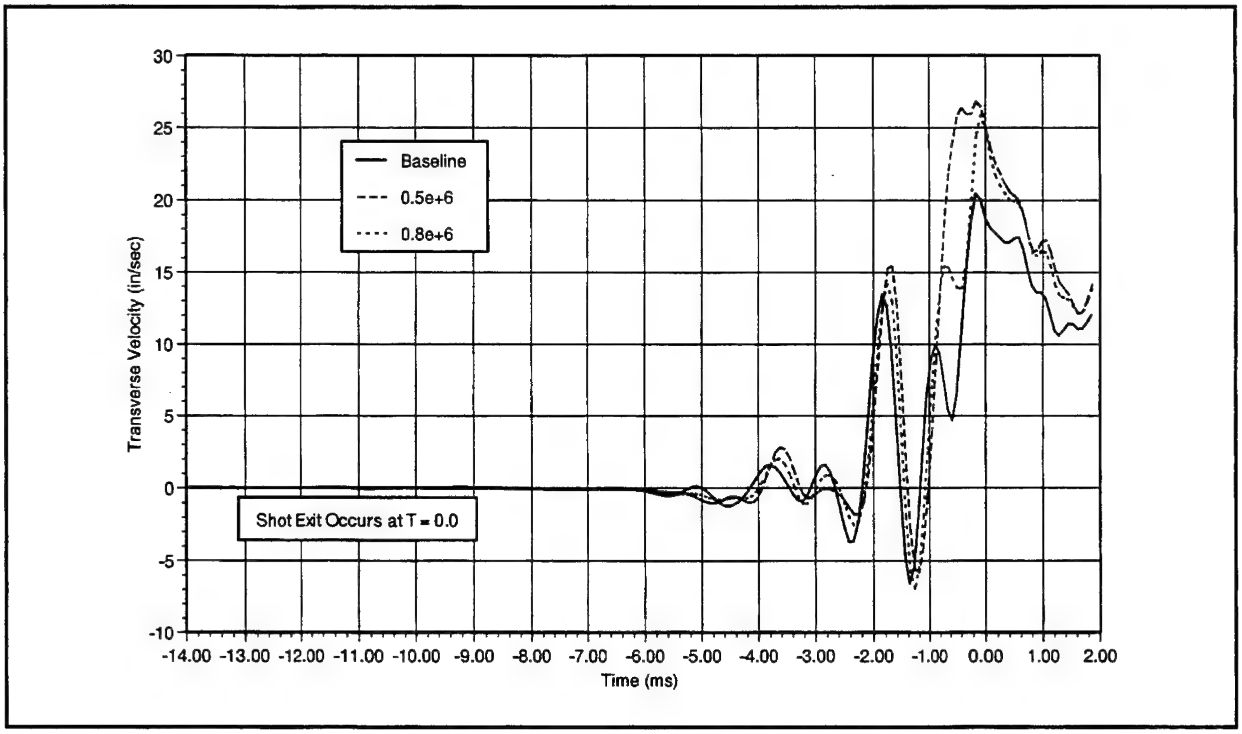

Figure 9. Transverse velocity of gun muzzle (S/N 518) using base and softer spring constants of forward bourrelet.

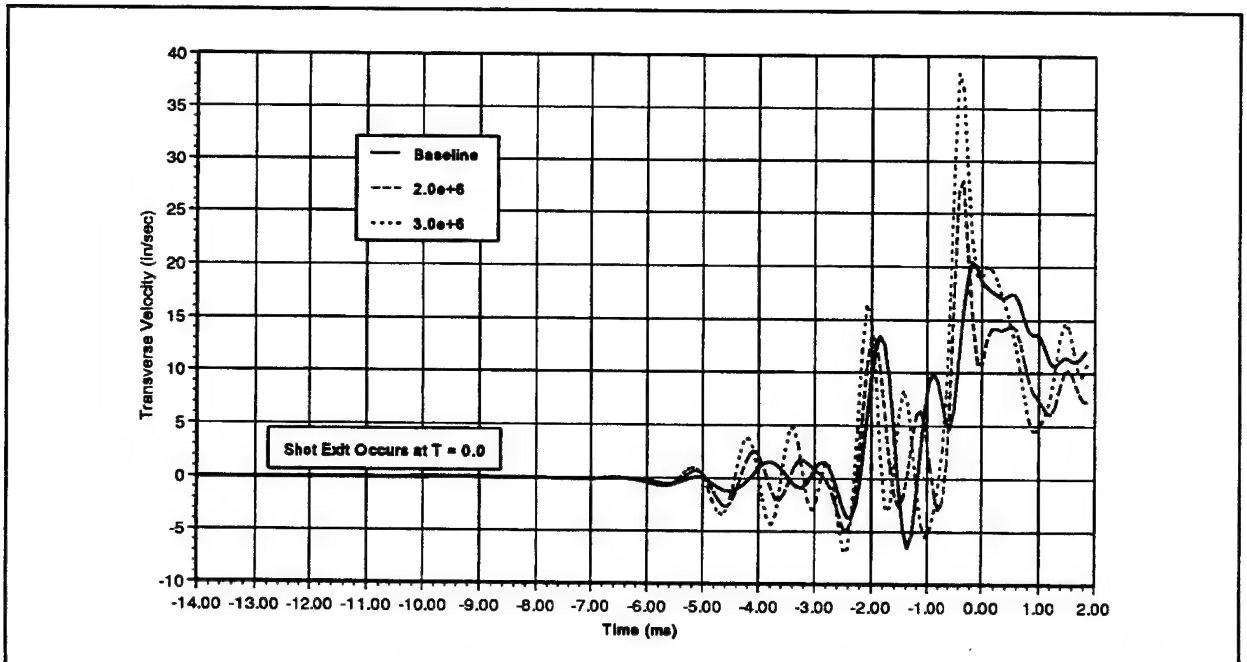

Figure 10. Transverse velocity of gun muzzle (S/N 518) using base and harder spring constants of forward bourrelet.

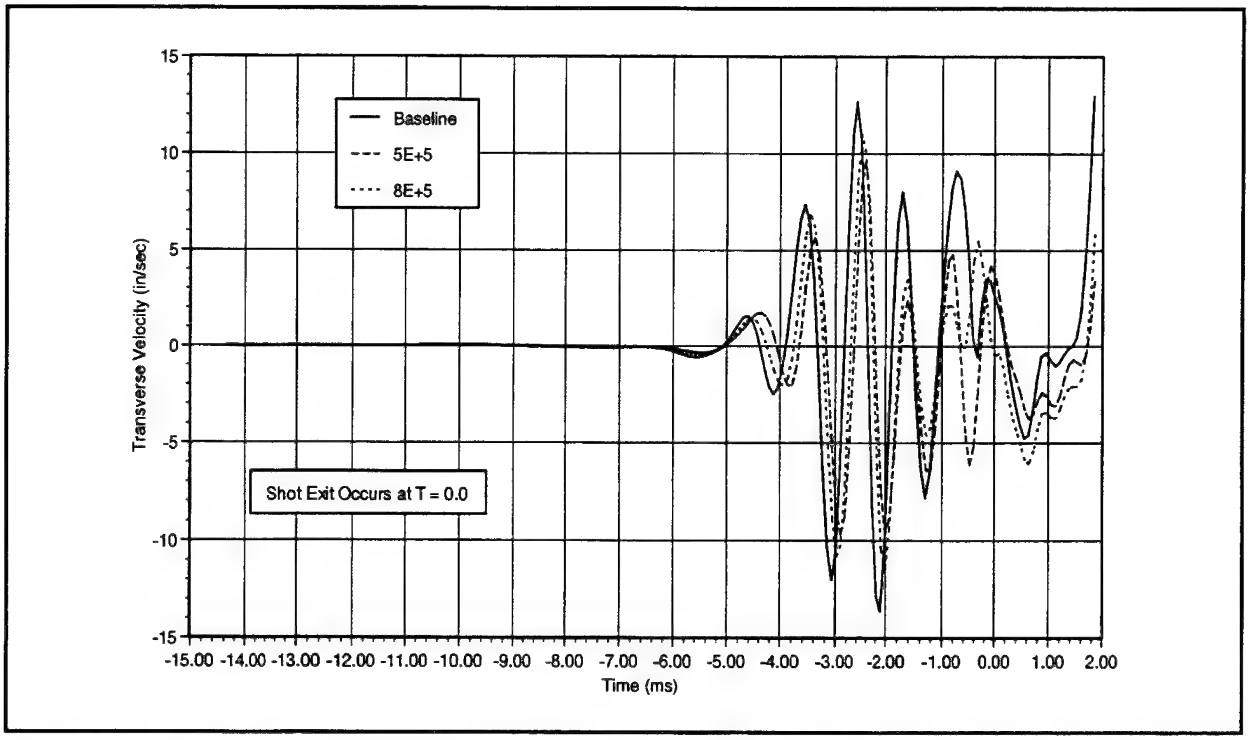

Figure 11. Transverse velocity of gun muzzle (S/N 17343) using base and softer spring constants of forward bourrelet.

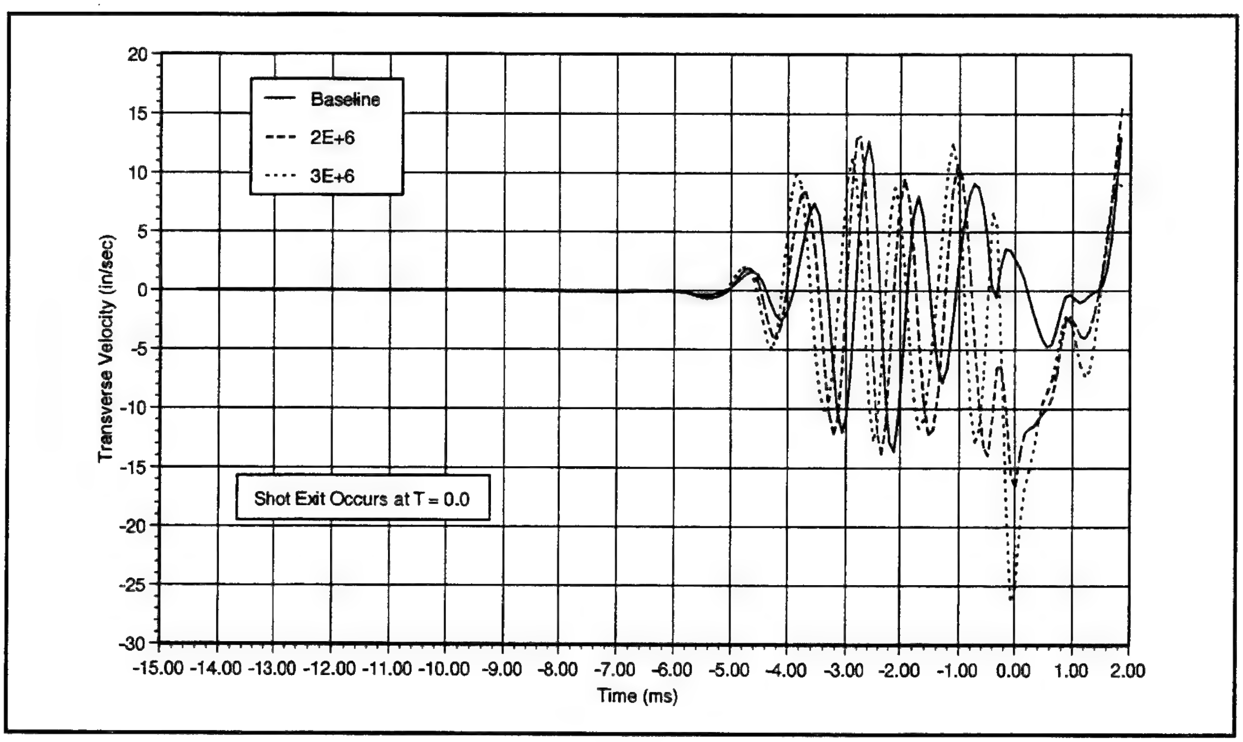

Figure 12. Transverse velocity of gun muzzle (S/N 17343) using base and harder spring constants of forward bourrelet.

These results prompted further investigation of the potential impact of changes to the forward bourrelet spring constant on range dispersion. Using the procedure previously described, a series of trajectory calculations was performed for each initial condition at a gun elevation corresponding to a nominal range of 7,500 yd (5,212 m). The results of these calculations are shown in Figures 13 and 14.

As expected, the changes in range dispersion that resulted from changes to the spring constant of the forward bourrelet are significantly larger than those for corresponding changes to the aft bourrelet. Although this study analyzed the response of only two individual gun barrels, these results would seem to indicate that if further improvements in the ballistic dispersion of the 5"/54 gun system are to be realized, then attention must be focused on the gun barrel manufacturing process with the objective of producing gun barrels whose characteristic centerline variations are more consistent.

5. SUMMARY AND CONCLUSIONS

The ballistic tools used in this study are proven products. They are fast, and as shown in this report, produce reasonable first-order results. Utilizing the analysis methodology described in this report, these models produce estimates of the ballistic dispersion of the 5"/54 gun system, that compare favorably to available proving ground data. In addition, these simulations were used to analyze the effect on shot exit conditions due to changes on a single, major parameter of the gun mount or the projectile. The results of these analyses indicate that major changes in the spring constant of the gun supports produce negligible effects on the projectile at shot exit. Much more noticeable changes in shot exit conditions occur when the projectile's contact spring coefficient changes. This is especially true when the forward bourrelet spring constant is changed.

One of the more important conditions to note in this gun system is that the very small center of gravity offsets in the breech have an insignificant effect on the dynamic response of the gun. The results indicate that each individual gun barrel centerline produces a unique gun response. This unique response appears to cause the mean achieved range for a fixed set of firing conditions to be

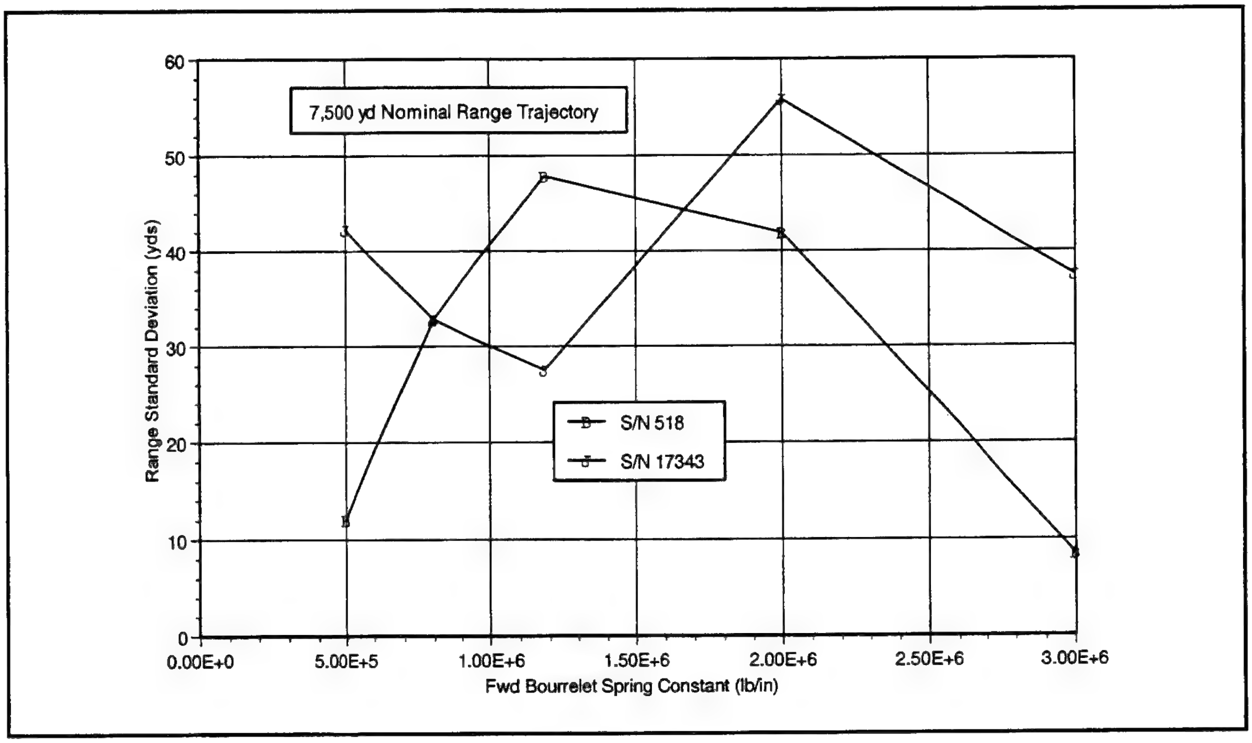

Figure 13. <u>Effect of variations in forward bourrelet spring constant</u>.

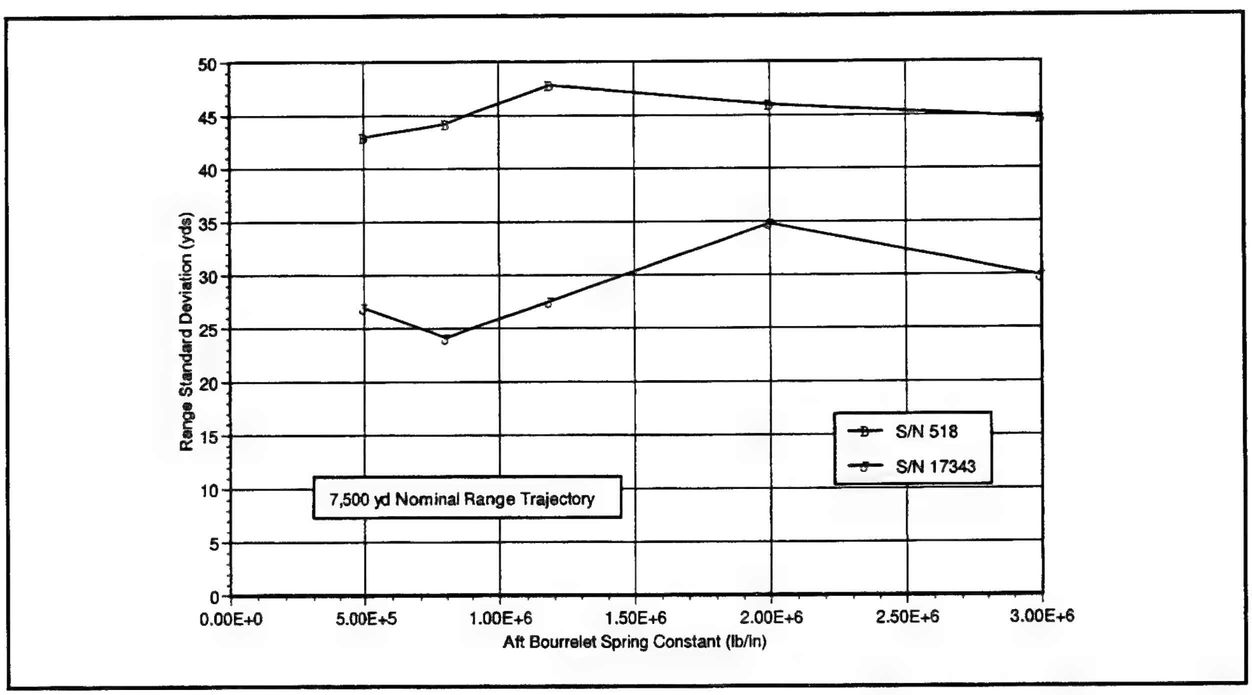

Figure 14. <u>Effect of variations in aft bourrelet spring constant</u>.

different for each gun barrel. This unique response may be the root cause of the short shooter or long shooter characteristic often observed in the 5"/54 and other long-range-type gun systems.

The analyses conducted during this investigation have yielded a considerable volume of information about the overall dynamic response characteristics of the 5"/54 gun system. A complete presentation of the data derived to date is far beyond the scope of this report. The interpretation of this information is an ongoing process and will undoubtedly lead to a more complete understanding of the key factors that influence the ballistic dispersion of the Mk 45 gun mount.

While the dynamic response of large-caliber indirect-fire gun systems is a relatively minor contributor to the overall delivery error, the importance of understanding the magnitude and source of all errors cannot be overstated. As the range of indirect-fire gun weapon systems is increased and greater emphasis is placed on improving delivery accuracy at these extended ranges, the need to identify, quantify, and understand the interdependencies of all sources of error will become increasingly important. Because of the ever-increasing cost of conducting live firing tests, computer modeling and simulation are often the only affordable means available to acquire the necessary knowledge and understanding necessary to make intelligent decisions concerning the overall accuracy potential of a gun weapon system. However, as the speed and power of computers have continued to increase, so have the sophistication and complexity of the models. Although these models are capable of providing precise information, often at levels of detail heretofore impossible to instrument, the time and expense required to develop and calibrate these models for existing weapon systems are often prohibitive. Therefore, there is a definite need for an accurate and simple means of conducting the quick-look-type analyses and first-order effect assessments necessary to guide and focus the application of more sophisticated techniques.

Although this study has admittedly been limited in scope, the authors believe that the analysis methodology developed during the investigation and described in this report offers a relatively simple and effective means of characterizing the dynamic response of a large-caliber gun system and assessing that system's sensitivity to changes in key parameters that affect its dynamic response. This

desktop procedure provides the gun and ammunition designer with an effective tool to quickly and economically assess the potential impact of proposed changes to key system parameters and can also provide design guidance during the early stages of new system development.

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13. ABSTRACT ***(Maximum 200 words)***

The U.S. Navy's 5-in 54-cal. (5"/54) gun system Mark (Mk) 45 was subjected to first-order dynamic analysis tools that allowed rapid assessment of ballistic dispersion of a typical naval high explosive projectile.

The interior ballistics high-velocity gun version 2 (IBHVG2) modeled the 5-in propelling charge Mk 67, and gun barrel centerline data were obtained from two 5"/54 Mk 19 gun barrels. The "Little RASCAL" program was used to estimate the tipoff angles and angular rates for the Mk 64 5-in projectile, and the "PC-PRODAS" computer program was used to estimate the projectile yaw and yaw rates resulting from the bore and bourrelet clearance. The tipoff angles and rates obtained for the Little RASCAL program were then combined with the yaw data to establish a matrix of possible worst-case conditions of initial projectile yaw and yaw rate.

A total of 32 possible muzzle exit conditions were identified and used as initial conditions for a 6 degrees of freedom trajectory program. The resulting variation in range obtained from the 32 trajectory calculations was used to calculate the range probable error. The results obtained from this relatively simple analysis technique have shown very good correlation with ballistic dispersion measurements made during actual firing tests.

14. SUBJECT TERMS
in-bore projectile dynamics, gun dynamics, shot exit conditions, ballistic dispersion, ballistic trajectory

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